



D2

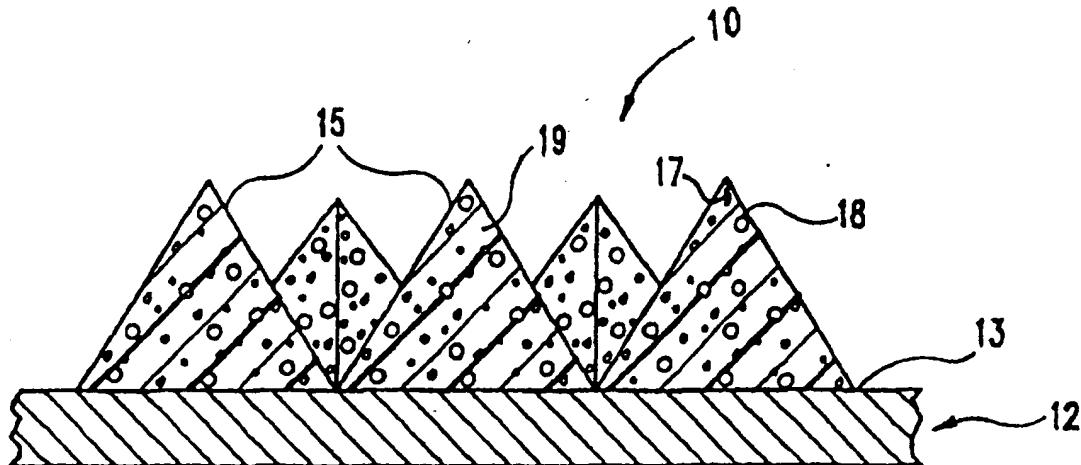
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> :  B24D 3/28, 11/00		A1	(11) International Publication Number: <b>WO 98/03306</b>
			(43) International Publication Date: 29 January 1998 (29.01.98)
<p>(21) International Application Number: PCT/US96/12110</p> <p>(22) International Filing Date: 23 July 1996 (23.07.96)</p> <p>(71) Applicant (for all designated States except US): MINNESOTA MINING AND MANUFACTURING COMPANY [US/US]; 3M Center, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).</p> <p>(72) Inventors; and</p> <p>(75) Inventors/Applicants (for US only): LUNDEGARD, Bruce, J. [US/US]; 2707 Hillvale Trail North, Oakdale, MN 55128 (US). WOO, Edward, J. [US/US]; 3294 York Alcove, Woodbury, MN 55125 (US). BALL, Andrew, J. [GB/US]; 2150 Sycomore Trail, Woodbury, MN 55125 (US).</p> <p>(74) Agents: FRANCIS, Richard et al.; Minnesota Mining and Manufacturing Company, Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).</p>		<p>(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p>	

## Published

With international search report.

(54) Title: STRUCTURED ABRASIVE ARTICLE CONTAINING HOLLOW SPHERICAL FILLER



## (57) Abstract

An abrasive article comprising a plurality of composites (15), where the composites comprise abrasive particles (17) and hollow spheres (18) dispersed in a binder (19). The structured abrasive article of this invention is fabricated at substantially reduced cost without sacrificing product performance.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

STRUCTURED ABRASIVE ARTICLE  
CONTAINING HOLLOW SPHERICAL FILLER

DESCRIPTION

BACKGROUND OF THE INVENTION

5

*Field of the Invention*

The present invention relates to an abrasive article having abrasive composites comprising abrasive particles and hollow spheres dispersed in a binder.

10

*Description of the Related Art*

A coated abrasive article has been described which incorporates hollow microspheres in a size and/or make coat layer located in-between a backing and an abrasive grain 15 coating (U.S. Pat. No. 4,543,106 (Parekh)). The microspheres in Parekh reside in a relatively flat-surfaced resin coating (make and/or size), whereas the abrasive grains principally rest upon and project from the surface of the make coat resin layer. This scheme, as disclosed by 20 Parekh, is indicated to enhance certain impact, thermal stress, adhesion, body stiffness, tear, and cracking characteristics of such a conventional coated abrasive of the type premised on a variegated and stratified make/grain/size coating scheme.

25 More recently, structured abrasive articles have been developed which involve a deployment of a plurality of precisely-shaped composites on a common backing, where the composites are individual abrasive formations adhered to the common backing in which each composite basically 30 involves a dispersion of abrasive particles throughout a binder matrix; e.g., see U.S. Pat. No. 5,152,917 (Pieper et al.); U.S. Pat. No. 5,454,844 (Hibbard et al.); PCT Inter. Public. No. WO 95/07797 (Hoopman et al.); U.S. Patent No.

5,378,251 (Culler et al.); U.S. Patent No. 5,453,312 (Haas et al.); U.S. Patent No. 5,454,750 (Cosmano); U.S. Patent No. 5,489,235 (Gagliardi et al.); and U.S. Patent No. 5,500,273 (Holmes et al.).

5        The structured abrasive articles, among other things, can both cut and refine the surface finish of an abraded surface in a single abrading operation. This capability is extremely important since the conventional approach of sequentially using separate abrasive articles of different 10 grades (viz., coarse to finer) can be reduced or even eliminated by use of structured abrasives.

15      The inclusion of filler of solid particulate forms in such composites of structured abrasives has been disclosed, such as in PCT Inter. Public. No. WO 95/07797 (Hoopman et al.). Abrasive articles having abrasive agglomerates of abrasive grain, binder and solid filler are described in U.S. Patent No. 4,652,275 (Bloecher et al.); U.S. Patent No. 4,799,939 (Bloecher et al.); and U.S. Patent No. 5,039,311 (Bloecher).

20      One type of refinement that has been made to abrasive composites formulations used in making structured abrasives involves incorporating relatively softer materials, e.g., polyethylene glycol or silicone oil, into the binder matrix of the abrasive composites; e.g., see U.S. Patent No. 25 5,453,312 (Haas et al.). This modification is made to enhance the erodability of the composites. Altering the erodability of the composites using relatively soft materials in conjunction with the hard materials (viz., resin binder, abrasive particles) of an abrasive composite 30 can affect the aggressiveness of the abrasive article. The desirability of this effect may depend on the ultimate use envisioned for the abrasive article.

35      Therefore, it can be appreciated that further refinements and advances in the important technology embodied by structured abrasives should be of interest and value to the abrasive industry.

## SUMMARY OF THE INVENTION

The present invention provides a structured abrasive article fabricated at substantially reduced cost without sacrificing product performance. An abrasive article of the present invention is particularly useful in certain applications, such as for example, abrading painted surfaces.

To accomplish these and other objectives, the present invention provides an abrasive article comprising a plurality of composites, where the composites comprise abrasive particles and hollow spheres dispersed in a binder.

In particular, the invention provides an abrasive article comprising a plurality of abrasive composites attached to a backing, the composites comprising abrasive particles and hollow spheres dispersed in a binder, wherein the abrasive particles comprise at least about 10 vol. % and the hollow spheres comprise at least about 15 vol. %, respectively, of the total volume of the composites.

In general, the hollow spheres comprise hollow spherical bodies or balloons formed of glass or ceramic, or a temperature-resistant polymeric material. The hollow spheres are "microspheres", and are occasionally referred to as such herein, in the sense that the hollow spheres have a diameter of from about 4 to about 250 micrometers and a median diameter of from about 25 to about 125 micrometers, although both larger and smaller diameters could also be useful. Such hollow spheres generally have a shell thickness of from about 3 to about 15% of the diameter of the hollow sphere. Preferably, the average volume percentage occupied by the hollow spheres in the abrasive composites is at least about 15, more preferably at least about 25, and most preferably between about 35 and about 50. In one preferred embodiment, the hollow spheres

are uniformly dispersed throughout the materials forming the abrasive composites.

In one preferred embodiment, the abrasive composite comprises between about 25 to about 45 volume percent glass 5 bubbles (as the hollow spheres) and 10 to 25 volume percent silicon carbide abrasive particles. Besides glass, other ceramic materials such as fly ash (a by-product of coal combustion), alumina, and clay, as well as temperature-resistant polymers, such as phenolics and polyurethane-10 polyurea thermoplastic polymers, can be used to form the shells of the hollow spheres. In an optional embodiment of this invention, the hollow spheres may be coated with a coupling agent (e.g., silanes, titanates, zircoaluminates) and/or resinous material to promote adhesion to the binder 15 matrix of the composites.

Unlike many solid inorganic fillers having relatively high densities, low density hollow spheres used in the present invention contain entrapped gas. The binder matrix of the abrasive composites is filled with and encapsulates 20 the hollow spheres to form a closed cellular-like structure.

It has been discovered that the incorporation of the hollow spheres into the abrasive composites of a structured abrasive article results in significant savings in resin 25 and abrasive particle costs. The hollow spheres take up a considerable percentage of the volume of the abrasive composites that otherwise would be occupied by abrasive particles and/or resin. Consequently, the inclusion of the hollow spheres in the abrasive composites effectively reduces the amount of binder resin and abrasive particles required and thereby extends the supply of these production materials. This translates into a substantial cost reduction in the fabrication of the abrasive article. Surprisingly, even where relatively large volume 30 percentages of hollow spheres are incorporated into the composites, no appreciable decrease in the cut rate of the

abrasive article is observed even though the amount of abrasive particles in the composite is greatly reduced.

Additionally, inclusion of the hollow spheres in the composites of a structured abrasive also has allowed an 5 increase in the resin to abrasive particles ratio within the slurry while maintaining acceptable cut performance. This increase in the resin to abrasive particles ratio within the slurry is achieved while maintaining and without 10 sacrificing acceptable cut performance. This increase in the resin to abrasive particles ratio effectively reduces the viscosity of the slurry to a more processable level while reducing the amount of abrasive particles needed to achieve the same result.

In one preferred embodiment of the invention, the 15 hollow spheres are formed with shells that are either translucent or transparent materials. As a consequence, radiation, such as ultraviolet (U.V.) and/or visible light, used to effect cure of the binder resin in the abrasive composites can transmit more easily through the composite, 20 resulting in more extensively cured binder. Moreover, another advantage of the enhanced passage and penetration of the radiation through the binder matrices of the composite, as enabled by the hollow spheres, is that slurries comprising relatively darker colored abrasive 25 particles, such as black silicon carbide, ceria or diamond, or other opaque abrasive particles, can be thoroughly cured.

Other features, advantages, and constructs of the invention will be better understood from the following 30 description of figures and the preferred embodiments of the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional side view of one 35 embodiment of the abrasive article of the present invention.

FIG. 2 is a cross-sectional side view of another embodiment of the abrasive article of the present invention.

5 FIG. 3 is a cross-sectional side view of yet another embodiment of the abrasive article of the present invention.

10 FIG. 4 is a side schematic showing an apparatus for making an abrasive article of the present invention.

10 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS  
OF THE INVENTION**

15 The abrasive article of the present invention has the general arrangement of a plurality of abrasive composites bonded to a backing, where reductions in overall production material costs are attainable without sacrificing performance by virtue of an inventive modification of the abrasive composite formulation and resulting structure.

20 The abrasive article of the present invention is particularly useful in certain applications such as paint sanding. The general construction of abrasive composites bonded to a backing to provide a structured abrasive article has been disclosed, for example, by U.S. Patent Nos. 5,152,917 and 5,304,223 (Pieper et al.) and 5,435,816 (Spurgeon et al.). However, an important aspect of this present invention is that the abrasive composites contain a plurality of hollow spheres in addition to the abrasive particles and binder (and any other solid components) constituting the composites.

30 The present invention can be even better understood by reference to the following discussion of the figures. It is to be understood that the enlarged features shown in the Figures 1-3 are merely illustrative, and are not necessarily drawn to exact scale.

35 FIG. 1 shows abrasive article 10 comprising a backing 12 having front surface 13. On front surface 13 supports composites 15 attached thereto. Composites 15 are three-

sided pyramids (not including the base side). The composites 25 each comprise abrasive particles 17, hollow spheres (bubbles) 18, and binder 19.

FIG. 2 shows abrasive article 20 representing another embodiment of the present invention. Abrasive article 20 comprises composites 25 on backing 12. However, in this embodiment, the composites 20 are formed in the shape of truncated, four sided pyramids (including the top plateau surface, but not the base side). Composites 25 comprise abrasive particles 17, hollow spheres (bubbles) 18, and binder 19. In the case of truncated pyramids, the volume percentage of the hollow spheres 18 in composites 25 is greater than that for composites 15 of abrasive article 10. Although not desiring to be bound to any theory, this proviso may permit the truncated pyramids to be more erodible to compensate, among other things, for the lack of a sharp abrading peak so that initial abrading action available is sufficiently aggressive.

Fig. 3 shows abrasive article 30 representing yet another embodiment of the present invention in which the volume percentage of the larger hollow spheres represents relatively large percentage of the composite volume, especially as compared to the relatively smaller volume percentage occupied by the smaller hollow spheres in the abrasive article 20 depicted in FIG. 2. In FIG. 3, composites 35 are truncated, four-side pyramids supported on backing 12. Composites 35 comprise abrasive particles 17, hollow spheres (bubbles) 18, and binder 19. As can be seen, hollow spheres 18 in composites 35 have a much larger diameter than bubbles 18 in composites 25. In certain embodiments, the bubbles may be so large as to fill a substantial portion of the composite. If the diameter of the bubbles is larger, or close to, the dimensions of the abrasive composite, it may not be possible to get more than one bubble per composite. It is preferred that at least one bubble is located in each abrasive composite.

As also can be seen in the depictions of FIGs. 1-3, some of the hollow spheres are situated in the immediate surface regions of the composites and, among these, some have partly exposed surfaces. This is a natural 5 consequence of the blending of the hollow spheres throughout the binder matrix. Prior to usage in an abrading operation, the vast majority of the hollow spheres typically will be completely embedded within the binder matrix of the composites and will only be subject to 10 exposure during an actual abrading operation as consequence of composite erosion. However, the initial exposure of some hollow spheres poses no drawback, and it may be helpful in promoting the initial breakdown of any composite tips.

15

#### **Abrasive Composites**

A successful abrasive article is one that is able to provide a high cut rate, while maintaining a sufficiently low surface finish on a workpiece, i.e., Ra and Rz. 20 Additionally, the abrasive article preferably has a long useful working life. The cut rate, surface finish, and generally article life, depend on the composition of the composite. Many times, the desired properties are directly adverse. For example, a low (and desirable) surface finish 25 may simply be the result of a very low cut rate. Alternately, an abrasive article with a high cut rate may abrade so quickly and coarse that several sequential grades of abrasive articles are needed in order to refine the surface finish. The topography, abrasive particles, any 30 fillers, and bubbles are important constituents in a useful abrasive article.

#### Topography

The abrasive composite is a three dimensional 35 structure having a shape defined by boundaries. It is generally preferred in the present invention that each

abrasive composite has a precise shape associated with it. The precise shape is determined by distinct and discernible boundaries. A boundary of the composite means the exposed surfaces and edges of the composite that delimit and define 5 the outline or contour of the actual three-dimensional shape of the abrasive composite. These boundaries separate one abrasive composite from another to some degree. These boundaries are readily visible and discernible when a cross-section of an abrasive article of this invention is 10 viewed under a scanning electron microscope.

Such precise shapes can be formed, for example, by at least partially curing the curable binder of a flowable mixture of an uncured binder precursor, abrasive particles, and the hollow spheres, while the mixture is both being 15 formed on a backing and filling a cavity on the surface of a production tool, and then removing the cured binder to form a composite. By comparison, in an abrasive article that does not have a precise shape, the boundaries are not definitive, e.g., where the abrasive composite is permitted 20 to sag before completion of its curing (solidification). Such non-precise composites are also within the scope of the present invention and can be formed, for example using a rotogravure roll or curing the binder precursor after it is removed from the cavity of the production tool.

25 The abrasive article of this invention is occasionally referred to herein as a "structured abrasive," which means a deployment of a plurality of the shaped abrasive composites on a common backing. The abrasive composites can be attached to the backing in-situ during their 30 formation and solidification, or, alternatively, the composites can be preformed (solidified) as separate, distinct three-dimensional shaped particles which can be attached to a backing via an additional binder. In either instance, the hollow spheres will be incorporated into the 35 binder slurry being used to prepare the composites per se.

Examples of useful composite shapes include, but are not limited to, pyramids, truncated pyramids, cones, truncated cones, cylinders (posts), and tapered posts. Preferably, shapes such as pyramids have between 3 and 10 5 sides (not including the base). Additional useful shapes include crosses (right angle intersection), X's, spheres, hemispheres, or any prismatic shape. The surfaces of the composite can be either smooth, i.e., flat, undulated, or dimpled such as a golf ball surface. Examples of useful 10 composite shapes and topographies are further described in PCT Inter. Public. Nos. WO 95/07797 (Hoopman et al.) and WO 95/122436, which descriptions are incorporated herein by reference. An abrasive article may have several different types of composite shapes. These different shapes can be 15 arranged in an array (i.e., a plurality of composites having the same shape), or individually. Alternatively, the abrasive composite can be randomly arranged on the backing surface.

The heights of the composites can be between 25 and 20 1600 micrometers, preferably between 40 and 1040 micrometers, and most preferably between 40 and 700 micrometers, although larger and small composites may also be useful. It is preferred that the height of the composites is essentially the same throughout the abrasive 25 article. However it is possible for the height of the composites to vary from one composite to another.

The density of the composites can be between about 5 and about 15,000 composites per square centimeter, preferably between about 2,000 and about 10,000 composites 30 per square centimeter. A higher density of composites provides a lower unit pressure per each composite, which generally may result in less severe scratching and a finer surface finish.

Hollow Spheres

The hollow spheres incorporated into the abrasive composites used in the abrasive articles of the present invention generally have a diameter of from about 4 to 5 about 250 micrometers, typically between 4 to 50 micrometers, and the median diameter of the hollow spheres is from about 25 to about 125 micrometers, although both larger and smaller diameters could also be useful. Such hollow spheres generally have a shell thickness of from 10 about 3 to about 15% of the diameter of the hollow sphere. Preferably, the volume percent of hollow spheres in the abrasive slurry forming the abrasive composite is at least about 15, more preferably at least about 25, even more preferably at least about 35, and most preferably between 15 about 35 and 50. In one preferred embodiment, the abrasive composite comprises between about 25 to 45 volume percent glass bubbles (as the hollow spheres) and 10 to 25 volume percent silicon carbide abrasive particles.

Besides glass, other ceramic-type materials such as 20 fly ash (a by-product of coal combustion), alumina, and clay, as well as temperature resistant polymers, such as phenolics, polyolefins, polyvinylidene dichloride or polyurethane-polyurea thermoplastic polymers, can be used to form the shells of the hollow spheres. In an optional 25 embodiment of this invention, the hollow spheres may be coated with a coupling agent (e.g., silanes, titanates, zircoaluminates) and/or resinous material to promote adhesion to the binder matrix of the composites.

Incorporation of relatively large amounts of hollow 30 spheres, in terms of the ranges indicated herein, effectively decreases the cost of producing the abrasive article. The reason being that a large percentage of the relatively expensive resin, mineral and/or solid fillers can be replaced with the relatively less expensive hollow 35 spheres.

Also, radiation, such as UV and visible light, or a combination of UV and visible, can pass through the composite more easily, providing in some instances an easier penetration of the UV light into the abrasive 5 slurry. Another advantage of the higher passage of radiation through the composite is that slurries comprising darker abrasive particles, such as black silicon carbide, ceria or diamond, are relatively easier to cure and crosslink the binder precursor to form a binder.

10 By the addition of such large volume percentages of bubbles, it is surprising that no appreciable decrease in the cut rate of the abrasive article is seen, even though the amount of abrasive particles in the composite is greatly reduced.

15 It is preferred that the hollow spheres are either translucent, transparent, or light in color. This allows the hollow spheres to transmit light instead of blocking or absorbing light directed into the composites. However, 20 dark bubbles, such as black or gray, can also be used. In certain embodiments, such as when dark bubbles, fillers, or resins are used, it may be preferable to cure the binder precursor using an electron-beam radiation source.

25 "Spheres" or "spherical", as used herein, mean particles having a true spherical shape from a geometric standpoint, as well as curved surface particles which vary from true spheres by as much as about 0.5 as calculated by the ratio of the smallest diameter/largest diameter.

For a given external hollow sphere diameter the density is a function of the wall thickness, which, in 30 turn, affects the mechanical resistance (especially to crushing) of the hollow spheres.

Examples of usable glass bubbles as the hollow spheres include those available from 3M Company under the trade designation "Scotchlite". Particular "Scotchlite" glass 35 bubble grades include: "S22", 5 to 125 micrometer diameter bubbles with a median of 50 micrometers, and 0.6 micrometer

thick walls; "S60", 5 to 125 micrometer diameter bubbles with a median of 50 micrometers, and 2.0 micrometer thick walls; "S15", 10 to 100 micrometer diameter bubbles with a median of 60 micrometers, and 0.6 micrometer thick walls; 5 "S32", 5 to 90 micrometer diameter bubbles with a median of 40 micrometers, and 0.6 micrometer thick walls; "S38", 5 to 100 micrometer diameter bubbles with a median of 45 micrometers, and 0.6 micrometer thick walls; and "K1", 10 to 200 micrometer diameter bubbles with a median of 70 10 micrometers, and 0.5 micrometer thick walls.

The terminology "glass" and "glass bubbles", as used herein in connection with the hollow spheres, is meant to at least include fused silica-based glasses, borosilicate glass, soda-lime glass, and so forth. Preferably, 15 vitreous, rigid, friable state glass is used for the shell material of the glass bubbles.

An example of a resin bubble is a polyvinylidene dichloride microsphere, commercially available from Pierce & Steven Industrial Group under the trade designation 20 "Miralite 177", 10 to 60 micrometer diameter bubbles with a median of 30 micrometers.

In some instances, it is preferred that the size distribution of the bubbles is fairly tight. However in some instances, such as when a high volume percentage of 25 bubbles is desired, it may be best to have a wide distribution of bubble sizes. A wide distribution of sizes will allow a tighter and denser, and thus higher, packing of bubbles in the composite. Further, at times it may be desirable to mix two types of bubbles. The two types of 30 bubbles could differ, for example, by their size distribution, median size, wall thickness, or composition material (e.g., glass, clay, polymer).

#### Abrasive Particles

35 It is preferred that the abrasive composites of the present invention comprise at least about 10 volume percent

abrasive particles, more preferably at least about 15 volume percent.

The abrasive particles useful for the composites of the inventive abrasive articles generally have a particle size ranging from about 0.01 to 1500 micrometers, usually between about 0.1 to about 400 micrometers, and preferably between 1 to 250 micrometers. The size distributions of the abrasive particles can be wide or narrow, and it is not necessary that the distributions be of a nominal grade (i.e., FEPA, ANSI, JIS, P-grade, etc.), although it is preferred that there be no extraneously large or small abrasive particles which may contribute to scratching or loading, respectively.

Examples of abrasive particles include fused aluminum oxide (which includes brown aluminum oxide, heat treated aluminum oxide, and white aluminum oxide), ceramic aluminum oxide, green silicon carbide, black silicon carbide, chromia, alumina zirconia, diamond, tin oxide, iron oxide, ceria, cubic boron nitride, titanium diboride, boron carbide, silica, garnet, and combinations thereof. The abrasive particles will typically have a Mohs' hardness of at least about 6, preferably at least about 7, and most preferably at least about 8.

The abrasive particles can also be shaped, for example, as thin bodies having geometrical faces of triangles, squares, or the like, and filamentary or rod shapes. Examples of useful shaped abrasive particles are described in U.S. Patent Nos. 5,090,968 (Pellow); 5,201,916 (Berg et al.); and 5,304,331 (Leonard et al.).

The term abrasive particle, as used herein, also encompasses single abrasive particles bonded together to form an abrasive agglomerate. Abrasive agglomerates are further described in U.S. Patent Nos. 4,311,489 (Kressner); 4,652,275 (Bloecher et al.); 4,799,939 (Bloecher et al.); 4,541,842 (Rostoker), and 5,500,273 (Holmes et al.), each description of which is incorporated herein by reference.

It is also within the scope of this invention to have a surface coating provided on the abrasive particles. The surface coating may have many different functions. In some instances the surface coatings increase adhesion to the 5 binder, alter the abrading characteristics of the abrasive particle, and the like. Examples of surface coatings include coupling agents, halide salts, metal oxides including silica, refractory metal nitrides and carbides, and the like.

10

#### Binder

The abrasive particles and hollow spheres are dispersed in an organic binder (matrix) to form the abrasive composite. The organic binder used in the 15 abrasive coating not only acts as a medium for additives, viz., the hollow spheres which may affect the erodability property of the composite, but the binder itself generally has some intrinsic ability to erode during an abrading operation.

20

The organic binder can be a thermoplastic binder, however, it is preferably a thermosetting binder. The binder is formed from a binder precursor. During the manufacture of the abrasive article, the thermosetting binder precursor is exposed to an energy source which aids 25 in the initiation and promotion of the polymerization or curing process. Examples of such energy source include thermal energy and radiation energy which includes electron beam, ultraviolet light, and visible light.

30

As a result of this polymerization process, the binder precursor is converted into a solidified binder. The binder in the abrasive composite is generally also responsible for adhering the abrasive composite to a front surface of a backing. However, in some instances there may be an additional adhesive layer provided at least between 35 the front surface of a backing and the abrasive composite.

There are two main classes of thermosetting resins, condensation curable and addition polymerized resins. The preferred binder precursors are addition polymerized resins because they can be readily cured by exposure to radiation.

5     Addition polymerized resins can polymerize through a cationic mechanism or a free radical mechanism. Depending upon the energy source that is utilized and the binder precursor chemistry, a curing agent, initiator, or catalyst is sometimes preferred to help initiate the polymerization.

10    Examples of typical binder precursors useful in this invention include phenolic resins, aminoplast resins having pendant  $\alpha,\beta$ -unsaturated carbonyl groups, urethane resins, epoxy resins, ethylenically unsaturated resins, acrylated isocyanurate resins, urea-formaldehyde resins, isocyanurate resins, acrylated urethane resins, acrylated epoxy resins, and mixtures thereof.

15    Phenolic resins are suitable and offer good thermal properties, availability, relatively low cost, and hardness. There are two types of phenolic resins, resole and novolac. Resole phenolic resins have a molar ratio of formaldehyde to phenol of greater than or equal to one to one, typically between 1.5:1.0 to 3.0:1.0. Novolac resins have a molar ratio of formaldehyde to phenol of less than one to one. Examples of commercially available phenolic resins include those known by the tradenames "Durez" and "Varcum" from Occidental Chemicals Corp., "Resinox" from Monsanto; and "Arofene" and "Arotap" from Ashland Chemical Co.

20    Aminoplast resins have at least one pendant  $\alpha,\beta$ -unsaturated carbonyl group per molecule or oligomer. These unsaturated carbonyl groups include acrylate, methacrylate, and acrylamide type groups. These materials are further described in U.S. Patent Nos. 4,903,440 (Larson et al.) and 5,236,472 (Kirk et al.), which both 25    incorporated herein by reference.

Epoxy resins have an oxirane ring structure and are polymerized by the ring opening. Such epoxide resins include monomeric epoxy resins and polymeric epoxy resins. The resins can vary greatly in the nature of their 5 backbones and substituent groups. For example, the backbone may be of any type normally associated with epoxy resin, and the substituent groups thereon can be any group free of an active hydrogen atom that is reactive with an oxirane ring at room temperature. Representative examples 10 of acceptable substituent groups include halogens, ester groups, ether groups, sulfonate groups, siloxane groups, nitro groups, and phosphate groups. Examples of some preferred epoxy resins include 2,2-bis[4-(2,3-epoxypropoxy)-phenyl]propane (diglycidyl ether of 15 bisphenol) and commercially available materials under the trade designation "Epon 828", "Epon 1004", and "Epon 1001F" available from Shell Chemical Co., "DER-331", "DER-332", and "DER-334" available from Dow Chemical Co. Other suitable epoxy resins include glycidyl ethers of phenol 20 formaldehyde novolac (e.g., "DEN-431" and "DEN-428" available from Dow Chemical Co.). Useful curing agents, viz., cationic curing agents, for the epoxy resins include those described in U.S. Patent No. 5,454,844 (Hibbard et al.), which description is incorporated herein by 25 reference.

Ethylenically unsaturated resins include both monomeric and polymeric compounds that contain atoms of carbon, hydrogen, and oxygen, and optionally, nitrogen, and the halogens. Oxygen or nitrogen atoms or both are 30 generally present in ether, ester, urethane, amide, and urea groups. Ethylenically unsaturated compounds preferably have a molecular weight of less than about 4,000 and are preferably esters made from the reaction of compounds containing aliphatic monohydroxy groups or 35 aliphatic polyhydroxy groups and unsaturated carboxylic acids, such as acrylic acid, methacrylic acid, itaconic

acid, crotonic acid, isocrotonic acid, maleic acid, and the like. Representative examples of acrylate resins include methyl methacrylate, ethyl methacrylate, styrene, divinylbenzene, vinyl toluene, ethylene glycol diacrylate, 5 ethylene glycol methacrylate, hexanediol diacrylate, triethylene glycol diacrylate, trimethylolpropane triacrylate, glycerol triacrylate, pentaerythritol triacrylate, pentaerythritol methacrylate, pentaerythritol tetraacrylate, and pentaerythritol tetraacrylate. Other 10 ethylenically unsaturated resins include monoallyl, polyallyl, and polymethallyl esters and amides of carboxylic acids, such as diallyl phthalate, diallyl adipate, and N,N-diallyladipamide. Still other nitrogen containing compounds include tris(2-acryloyl- 15 oxyethyl)isocyanurate, 1,3,5-tri(2-methacryloxyethyl)-s-triazine, acrylamide, methylacrylamide, N-methylacrylamide, N,N,-dimethyl-acrylamide, N-vinylpyrrolidone, and N-vinylpiperidone.

Acrylated urethanes are diacrylated esters of hydroxy 20 terminated NCO extended polyesters or polyethers. Examples of commercially available acrylated urethanes include "UVITHANE 782" available from Morton Thiokol Chemical, and "CMD 6600", "CMD 3500", "CMD 3600", and "CMD 3700" available from Radcure Specialties.

25 Bismaleimide resins are further described in U.S. Patent No. 5,314,513 (Miller et al.), which is incorporated by reference.

Regarding free radical curable resins, in some instances it is preferred that the abrasive slurry further 30 comprise a free radical curing agent. However in the case of the electron beam energy source, the curing agent is not always required because the electron beam itself generates free radicals. Examples of useful free radical thermal curing agents or initiators, or curing agents or 35 photoinitiators for use with ultraviolet or visible light energy sources, include those described U.S. Patent No.

5,454,844 (Hibbard et al.), which description is incorporated herein by reference.

Additives

5 The abrasive slurry used to form the abrasive composites can further contain optional additives, such as fillers (including grinding aids), surfactants, dyes, plasticizers, coupling agents, suspending agents, such as 10 thixotropic materials, antistatic agents, and the like. The amount of these materials, antistatic agents, and the like. 15 independently affect the erodability of the abrasive properties desired. The use of these additives can also composite. Among other things, the presence and amount of any of these optional additives should be selected so as not to adversely inhibit the function of the hollow spheres.

There are various ways in which to modify the abrasive articles according to the present invention. For example, 20 filler particles or other additives, may be added. Examples of optional solid fillers used for their supplemental effects on erodability include, but are not limited to marble, marl, gypsum, chalk, coral, coquina, and oolite. Other examples of useful filler for this invention 25 include: metal carbonates (such as calcium carbonate (chalk, calcite, marl, travertine, marble, and limestone), calcium magnesium carbonate, sodium carbonate, magnesium carbonate), silica (such as quartz, solid glass beads, and glass fibers), silicates (such as talc, clays (montmorillonite), feldspar, mica, calcium silicate, 30 calcium metasilicate, sodium sulfates (such as calcium sulfate, sodium sulfate, aluminum sulfite, aluminum aluminosilicate, and sodium sulfate), aluminum trihydrate, gypsum, vermiculite, wood flour, 35 calcium oxide (lime), aluminum oxide, and titanium dioxide), and metal sulfites (such as calcium sulfite).

Particularly useful filler additives include amorphous silica, such as commercially available from DeGussa under the trade designation "OX-50" and silica clay, such as commercially available from R.T. Vanderbilt Company, Inc., 5 under the trade designation "Peerless #4.

The term filler also encompasses materials that are known in the abrasive industry as grinding aids. A grinding aid is defined as particulate material that the addition of which has a significant effect on the chemical 10 and physical processes of abrading which results in improved performance. Examples of chemical groups of grinding aids include waxes, organic halide compounds, halide salts and metals and their alloys. The organic halide compounds will typically break down during abrading 15 and release a halogen acid or a gaseous halide compound. Examples of such materials include chlorinated waxes like tetrachloronaphthalene, pentachloronaphthalene; and polyvinyl chloride. Examples of halide salts include sodium chloride, potassium cryolite, sodium cryolite, 20 ammonium cryolite, potassium tetrafluoroborate, sodium tetrafluoroborate, silicon fluorides, potassium chloride, magnesium chloride. Examples of metals include, tin, lead, bismuth, cobalt, antimony, cadmium, iron, and titanium. Other miscellaneous grinding aids include sulfur, organic 25 sulfur compounds, graphite, and metallic sulfides.

Other optional additives useful in further altering the erodability of the abrasive coating include plasticizers such as polyethylene glycol and silicone oil, such as each commercially available from Union Carbide 30 under the trade designations Carbowax "600" and Silwet™ "L-7500" or "L77", respectively. Coupling agents added to the abrasive coating also alter the erodability of the coating by enhancing the cross-linking in the coating. Examples of coupling agents include silane coupling agents, such as 35 commercially available from Union Carbide under the trade designations "A-174" and "A-187". Examples of antistatic

agents include graphite, carbon black, vanadium oxide, and humectants.

Wetting agents are useful in controlling the viscosity of the abrasive slurry. It is desirable that the abrasive particles, bubbles, and any fillers are thoroughly wetted by the binder precursor. Storage of the abrasive slurry for an extended time, for example overnight, may improve the consistency of the slurry because the binder precursor has had ample time to thoroughly wet the particles.

10

#### Backing

The backing used in the abrasive article of this invention generally involves a sheet-like structure having a front and a back side, with the front side being available for attachment of the abrasive composites. The backing can be selected from among conventional abrasive backings. Examples of typical abrasive backings include polymeric film (including primed polymeric film), cloth (including greige cloth), open and closed cell sponges and foams, paper, vulcanized fiber, fibrous reinforced thermoplastics, nonwovens, metal (including metal substrates, metal foils, and the like), and treated versions thereof, and combinations thereof. Other examples of backings are described in U.S. Patent No. 5,316,812 (Stout et al.) and PCT Inter. Public. No. WO 93/12911 (Benedict et al.). The backing may contain a backing treatment, such as a primer, presize, backsize, and/or saturant. Alternatively, the backing may be devoid of any backing treatment.

It is also possible to directly apply the abrasive composite coating to an attachment system. For example, PCT Inter. Public. No. WO 95/19242 (Barry et al.) teaches the direct coating of precisely shaped abrasive composites onto a hook attachment material which is adapted for engagement to a loop or foam material. Alternately, the

abrasive composites can be formed on a loop material which is adapted for engagement with a hook or stalk material.

The backside of the backing may also contain a slip resistant or frictional coating. Examples of such coatings 5 include an inorganic particulate (e.g., calcium carbonate or quartz) dispersed in an adhesive.

#### Method of Making the Abrasive Article

The abrasive article of the present invention can be 10 in any known form, such as a sheet, tape, or endless belt. As explained herein, in one embodiment of this invention, the abrasive coating of the abrasive article is in the form of a plurality of abrasive composites shaped upon and bonded in situ to a backing, such as taught by U.S. Patent 15 Nos. 5,152,917 and 5,304,223 (Pieper et al.) and 5,435,816 (Spurgeon et al.). That is, the abrasive composites are conveniently formed on a backing by filling cavities in a production tool with an abrasive slurry comprising the abrasive particles, binder precursor, and hollow spheres 20 (and any other additives), and then curing the binder precursor while situated in molding cavities in the face of the production tool, such that the cured composite has the inverse shape of the cavity. A plurality of these abrasive composites, such as when formed together on a backing, 25 provide an abrasive article that is a structured abrasive article. The individual composites are generally interconnected by abutting each other at their bases, or via a land portion or abrasive material formed at the bases of the composites.

30 The preferred overall method, scheme and equipment useful to make a structured coated abrasive according to this invention is outlined and described in U.S. Patent Nos. 5,152,917 and 5,304,223 (Pieper et al.) and 5,435,816 (Spurgeon et al.), all incorporated herein by reference. Of 35 course, in the present invention, hollow spheres are also included in the preparation of the abrasive slurry. One

method involves 1) introducing an abrasive slurry onto a production tool, wherein the production tool has a specified pattern, 2) introducing a backing to the outer surface of the production tool such that the slurry wets 5 one major surface of the backing to form an intermediate article; 3) at least partially curing or gelling the resinous adhesive before the intermediate article departs from the outer surface of the production tool to form a lapping coated abrasive article; and 4) removing the coated 10 abrasive article from the production tool. Another method involves 1) introducing an abrasive slurry onto the backing such that the slurry wets the front side of the backing to form an intermediate article; 2) introducing the intermediate article to a production tool having a 15 specified pattern; 3) at least partially curing or gelling the resinous binder before the intermediate article departs from the outer surface of the production tool to form a structured abrasive article; and 4) removing the structured abrasive article from the production tool. In these two 20 methods, the resulting solidified abrasive slurry or abrasive composite will have the inverse pattern of the production tool. By at least partially curing or solidifying on the production tool, the abrasive composite has a precise and predetermined pattern. The resinous 25 binder can be further solidified or cured off the production tool.

FIG. 4 is a general schematic of a method for manufacturing the abrasive articles of the present invention. A backing 41 leaves an unwind station 42 and at 30 the same time the production tool 46 leaves another unwind station 45. An abrasive slurry is applied via coating means 44 to cavities in the face of the production tool 46 by means of coating station 44 to form an abrasive precursor coating 46'. It is possible to heat the abrasive 35 slurry and/or subject the slurry to ultrasonics prior to coating to lower the slurry viscosity. Other methods of

lowering the viscosity, such as increasing the amount of binder precursor and/or decreasing the amount of fillers, are well known. The coating station 44 can be any conventional coating means such as a drop die coater, knife 5 coater, curtain coater, vacuum die coater, or a die coater.

After the production tool is coated, backing 41 is brought into contact with production tool 46 and abrasive precursor coating 46' by means of contact nip roll 47 such that the abrasive precursor coating 46' wets the front 10 surface of the backing 41. The contact nip roller 47 also forces the resulting construction against rotatable support drum 43. The compression forces exerted by contact nip roller 47 and/or drum 23 necessary to intimately contact the binder precursor coating 46' with the front face of the 15 backing 41 are not great enough to crush the hollow microspheres embedded in the binder precursor coating 46' beyond any nominal scale, if any.

Next some appropriate form of energy is transmitted into the abrasive precursor coating 46' through intervening 20 production tool 46 to at least partially cure and solidify the binder precursor coating 46' by energy source 48 to form abrasive coating 46" which has become attached to the backing 41. The term partial cure means that the binder precursor coating is polymerized to such a state the 25 abrasive slurry does not flow when inverted in the tool. If the binder precursor coating 46' is only partly cured during its conveyance around drum 43, the binder precursor coating 46' can be fully cured by any convenient energy source at a later time once it is removed from the 30 production tool 46.

Abrasive coating 46" and backing 41 are removed from production tool 46 at an effective separation angle  $\alpha$  so that abrasive article 40 is formed, which is collected by wind-up on storage mandrel 49'. The production tool 46 is 35 collected by rewinding upon mandrel 49 so that the production tool can be re-used again.

The coating means arrangement illustrated in FIG. 4 is also suitable for an alternate embodiment where the backing layer and production tool layer are switched such that the backing is directly coated with the abrasive slurry at 5 coating station 44 and then the coated backing is brought into contact with the face of the production tool bearing the shaping cavities at contact nip roll 47. In this embodiment, the backing material is selected as one which will transmit radiation or thermal energy emanating from 10 energy source 48 to the abrasive precursor coating 46'.

Other details on the production tool, energy source, and other features of the fabrication scheme/equipment useful for making the abrasive article are outlined and described in U.S. Patent Nos. 5,152,917 and 5,304,223 15 (Pieper et al.) and 5,435,816 (Spurgeon et al.), all incorporated herein by reference.

Abrasive articles having composites which are not precisely shaped are also within the scope of the present invention. Abrasive articles commonly known as lapping abrasives or lapping films have been known to be made via rotogravure processes, see e.g., U.S. Patent Nos. 4,773,920 20 (Chasman et al.) and 5,014,468 (Ravipati et al.). Composites made by rotogravure rolls typically have a three-dimensional structure but generally do not have 25 precise and exact side walls. Another method to produce three-dimensional composites with imprecise structures is to cure the binder precursor after it has been removed from the production tooling. The composite precursor will typically slump somewhat before it is cured.

30

#### Workpiece

The abrasive article of the present invention can be used to abrade many different and diverse types of workpieces. Examples of workpieces include rolls, thin 35 film disks for magnetic media storage, painted surfaces, stained surfaces, plywood, glass lenses, wood panels, and

the like. The abrasive article of the present invention is particularly useful in abrading workpieces which has a tendency to provide substantial amounts of swarf which causes the abrasive article to load. Examples of such 5 workpiece surfaces include, for example, painted surfaces such as metals and woods, and plywood, particle board and other wood panels.

Objects and advantages of this invention are further 10 illustrated by the following examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this invention. All parts, 15 percentages, ratios, and so forth, in the examples are by weight unless otherwise indicated.

15

#### EXAMPLES

The following abbreviations for materials are used throughout:

AlSi        sodium aluminum silicate filler, commercially 20 available from DeGussa Corp. under the trade designation "P820";

ASC        amorphous silica clay, commercially available from R.T. Vanderbilt Co. under the trade designation "Peerless #4";

25        GB        hollow glass spheres (bubbles), commercially available from 3M Company under the trade designation "Scotchlite";

ITX        isopropyl-9H-thioxanthene-9-one, commercially 30 available from Sartomer Corp. under the trade designation "ITX";

PH1        2-methyl-1-(4-(methylthio)phenyl)-2-(4-morpholinyl)-1-propanone, commercially available from Ciba Geigy Corp. under the trade designation "Irgacure 907";

35        SCA        silane coupling agent, 3-methacryloxypropyl-trimethoxysilane, commercially available from

Union Carbide under the trade designation "A-174";

SiC silicon carbide abrasive particles;

SiCG green silicon carbide abrasive particles;

5 TATHEIC triacrylate of tris(hydroxy ethyl)isocyanurate, commercially available from Sartomer under the trade designation "368";

TMPTA trimethylol propane triacrylate, commercially available from Sartomer under the trade designation "351"; and

10 THF tetrahydrofurfuryl acrylate, commercially available from Sartomer Corp. under the trade designation "285".

15 Procedure for Making a Structured Abrasive Article

The following general procedure, from the teachings of U.S. Patent Nos. 5,152,917 (Pieper et al.) and 5,435,816 (Spurgeon et al.), both incorporated herein by reference, was used for making the structured abrasive articles of the 20 examples.

First, an abrasive precursor slurry was prepared by thoroughly mixing with a high shear mixer the raw materials as listed. The slurry was allowed to sit overnight, after which it was again mixed to redisperse any settled 25 particles. The slurry was at a temperature of about 30°C when it was coated at a speed of about 15 meters/minute with a knife coater using a 25-38 micrometer gap onto a production tool having recesses such that the abrasive slurry filled recesses in the tool. Next a latex saturated 30 paper backing was pressed against the filled cavities of the production tool by means of a roller and the abrasive slurry wetted the front surface of the backing. Visible light, at a dosage of about 236 Watts/cm (600 Watts/inch) produced by a "D" bulb, available from Fusion Systems, was 35 transmitted through the tooling and into the abrasive slurry. The visible light initiated the polymerization of

the binder precursor and resulted in the abrasive slurry, also known as the abrasive precursor coating, to be transformed into an abrasive composite with the abrasive composite being adhered to the cloth substrate. Next, the 5 abrasive composite construction was separated from the production tool to form an abrasive article.

#### Test Procedure I

For Test Procedure I, the abrasive article was 10 converted into a 10 cm (4 inch) diameter disc and secured to a foam back-up pad by means of a pressure-sensitive adhesive. The abrasive disc/back-up pad assembly was installed on a Schiefer testing machine, commercially available from Frazier Precision Co., Gaithersburg, MD., 15 and the abrasive disc was used to abrade a workpiece made of cellulose acetate butyrate polymer. The load was 4.5 kg. All of the testing was done underneath a water flood at a flow rate of 60 g of water per minute. Cut was recorded in grams. The endpoint of the test was 500 20 revolutions or cycles of the abrasive disc.

#### Test Procedure II

For Test Procedure II, the abrasive article was converted into a 3.5 cm diameter disc with scalloped edges. 25 The abrasive article was attached to a hand block and used to remove defects from a steel panel painted with clear coat paint over a black base. The sample was used to wet sand a paint spot for approximately 30 circular strokes to produce a scratch area of about 4-5 cm diameter. This 30 procedure was then repeated on a second paint spot with the same abrasive article. This procedure was repeated until the size of the resulting scratch spot was approximately 50% of the initial spot. The life of the product was assessed by the number of spots that could be sanded in 35 this manner. The surface finish of each spot was then measured.

Surface Finish

The Ra (Average Roughness) of a surface is defined as the arithmetic mean of all deviations from the center line 5 of the roughness profile within the total measuring length.

The Rz (Average Roughness Depth) is defined as the average of the difference between the highest peak and the lowest valley of each of 5 successive individual equal measuring lengths within total measuring length.

10 Ra and Rz were measured using a profilometer with a 0.005 mm radius stylus, a total measuring stroke length of 4.0 mm, and a cut-off value of 0.80 mm. The profilometer was a Perthometer having the trade designation PERTHEN M4P, from Feinprüf GmbH, Göttingen, Postfach 1853, D-3400, 15 Germany.

Examples 1, 2, and 3 & Comparative Example A

The abrasive articles investigated for Examples 1, 2, and 3 and Comparative Example A were produced according to 20 the above "Procedure for Making a Structured Abrasive Article". Table 1 below, lists the ingredients for the abrasive slurries used for the respective examples, as a percentage of volume. As the hollow sphere filler, Example 1 used "Scotchlite S22" glass bubbles; Example 2 used 25 "Scotchlite S60" glass bubbles; and Example 3 used "Scotchlite K1" glass bubbles. Comparative Example A was devoid of hollow sphere filler. The silicon carbide abrasive particles used were JIS Grade 1500.

The topography of the abrasive composites was four-30 side truncated pyramids, approximately 65 micrometers high. Density of pyramids was approximately 8900 composites/cm<sup>2</sup>.

Table 2 below, lists performance properties for the examples. Test Procedure I was performed to determine the cut performance on solid acrylic workpieces, using 4.5 kg 35 (10 pounds) and 500 revolutions. The surface finish of the

acrylic workpiece was tested. Results are recorded in Table 2 in microinches ( $\mu\text{m}$ ).

Table 1

	Examples 1, 2, 3	Comp. Ex. A
TATHEIC	9.02	13.18
TMPTA	10.85	15.86
THF	18.05	26.38
SCA	1.09	1.58
PH1	0.87	1.26
ITX	0.42	0.62
AlSi	0.65	1.22
ASC	3.52	6.65
SC	17.64	33.25
GB	37.89	0

5

Table 2

Example	Cut (grams)	Ra	Rz
1	0.8005	4.4967 (0.1142)	42.2180 (1.0721)
2	0.6609	4.5517 (0.1156)	40.6630 (1.0328)
3	0.8910	4.4950 (0.1142)	41.0520 (1.0427)
Comp. A	0.8695	4.6633 (0.1184)	43.2200 (1.0978)

#### Examples 4, 5, and 6 & Comparative Examples B-G

Table 3 below, lists the ingredients used in preparing 10 the abrasive slurries for these additional tested examples, in actual weight (grams) used.

The topography of the abrasive composites was four-side truncated pyramids, approximately 65 micrometers high, except Example 4 was produced with a four sided pyramidal 15 pattern where no two adjacent composites had the same

shape. This pattern, and its manner of being made, is described in USSN 08/120,300 (Hoopman et al.) filed 13 September 1993 and PCT Inter. Public. No. WO 95/07797, which are incorporated herein by reference. Two sizes of 5 pyramids were made, 178 and 355 micrometers high.

10 However, it is pointed out that for Example 6, PVDC (polyvinylidene dichloride) microspheres, commercially available from Pierce & Steven Industrial Group under the trade designation "Miralite 177", were used instead of the glass bubbles.

15 Table 4 below, lists the volume percentage of hollow spheres and total filler incorporated into the abrasive composites of the respective examples, and the cut achieved for each abrasive article according to Test Procedure I. The volume of total filler is the sum of the hollow spheres (glass bubbles or PVDC microspheres, as applicable) and ASC.

Table 3

Ex.	TATHEIC	TMPTA	THF	SCA	PH1	ITX	AlSi	ASC	Abr. Part.	GB
B <sup>1</sup>	25.86	60.34	70.3	3.9	0	3.1	1.5	6	320	0
C <sup>2</sup>	0	90.23	75.31	3.48	3.23	1.51	0	21.72	359.14	0
D <sup>3</sup>	0	90.23	75.31	3.48	3.23	1.51	0	21.72	359.14	0
E <sup>4</sup>	0	113.97	94.89	2.53	3.97	1.9	0	21.72	143.23	0
F <sup>5</sup>	0	103.3	85.85	3.96	3.68	1.96	0	21.72	258.89	0
G <sup>6</sup>	0	92.62	77.27	3.57	3.31	1.55	0	21.72	332.03	0
4	0	87.45	73.26	2.01	3.15	1.47	5.95	32.25	198	25
5 <sup>7</sup>	0	87.45	73.26	2.01	3.15	1.47	5.95	32.25	198	25
6 <sup>8</sup>	0	91.2	76.4	2.09	3.28	1.51	6.2	33.6	206.3	4.8

20 1: The abrasive particles for Comparative Example B consisted of 320 grams of grade 1000 SiCG.

2: The abrasive particles for Comparative Example C consisted of 359.14 grams of grade 1000 SiCG.

3: The abrasive particles for Comparative Example D consisted of 359.14 grams of grade 1000 SiC.

25 4: The abrasive particles for Comparative Example E consisted of 117.94 grams of grade 1000 SiC and 25.29 grams of grade 1200 SiC.

5: The abrasive particles for Comparative Example F consisted of 226.6 grams of grade 1000 SiC and 32.29 grams of grade 1200 SiC.

6: The abrasive particles for Comparative Example G consisted of 292.74 grams of grade 1000 SiC and 39.29 grams of grade 1200 SiC.

5 \*: The abrasive particles for Example 4 consisted of 198 grams of grade 1000 SiC.

†: The abrasive particles for Example 5 consisted of 198 grams of grade 1200 SiC.

‡: The abrasive particles for Example 6 consisted of 206.3 grams of grade 1000 SiCG.

10

Table 4

Example	Vol. % Hollow Spheres	Vol. % Total Filler	Cut (g)
B	0	0.9	0.446
C	0	2.86	0.394
D	0	2.86	**
E	0	3.05	0.036
F	0	2.89	0.106
G	0	2.93	0.216
4	34.4	37.6	0.389
5	34.4	37.6	0.426
6	34.4	37.6	0.321

\*\*: Example D failed to cure and could not be tested for cut.

15 Examples 7-13 & Comparative Example H

Table 5 below, lists the ingredients used in preparing the abrasive slurries for these additional tested examples, in actual weight (grams) used. For Examples 7-12, the abrasive particles consisted of grade 3000 SiC. The 20 abrasive slurry formulation of Example 13 was the same as Example 10 except that the abrasive particles for Example 13 consisted of grade 4000 SiC.

The topography of the abrasive composites was four-side truncated pyramids, approximately 65 micrometers high.

Table 6 below, lists the volume percentage of bubbles and total filler in the abrasive composites, and hand sanding life results as determined according to Test Procedure II. The volume of total filler is the sum of 5 hollow spheres (glass bubbles) and ASC.

Table 5

Ex.	TATHEIC	TMPTA	THF	SCA	PH1	ITX	AlSi	ASC	GB	Abr. Part.
H	25.86	60.34	70.3	3.9	3.1	1.5	5.87	0	0	198.64
7	26.93	62.83	73.19	4.06	3.22	1.56	5.87	0	18.3	265
8	26.61	62.08	72.33	4.01	3.19	1.54	5.87	0	24.8	233.7
9	25.86	60.34	70.3	3.9	3.1	1.5	5.87	0	31.83	0
10	25.86	60.34	70.3	3.9	3.1	1.5	5.87	31.8	24.6	195.22
11	25.86	60.34	70.3	3.9	3.1	1.5	5.87	0	31.62	116.5
12	25.86	60.34	70.3	3.9	3.1	1.5	5.87	0	59.76	50.3

10

Table 6

Example	Vol. % Bubbles	Vol. % Total Filler	hand sanding life
H	0	0	good
7	27.5	27.5	good
8	36	36	good
9	50	50	poor
10	36	39	good
11	46	46	good
12	50	50	poor

Tables 7 and 8 report the Ra and Rz, respectively, of the abrasive article samples of Examples 7, 8, 10, 11 and 12 as determined according to Test Procedure II. It is 15 desirable to provide both an Ra and Rz that are low while maintaining the ability to remove any defects. Results are recorded in microinches (one microinch = 0.0254  $\mu\text{m}$ ).

Before the test, i.e., at Stroke 0, the Ra and Rz measurements of the unsanded surface containing the defects were 2 and 11, respectively.

5

Table 7 - Ra

No. of Strokes	Example 7	Example 8	Example 10	Example 11	Example 12
30	3.5	3	3	3.5	2
60	2	2	3	3	2
90	2	2	4	2	2
120	2	2	3	2	2
150	2	2	2	2	2
180	2	2	2	2	2

Table 8 - Rz

No. of Strokes	Example 7	Example 8	Example 10	Example 11	Example 12
30	28	32	28	34.7	21
60	21	21	26	27	20
90	22	22	38	23	22
120	22	22	31	23	20
150	17	24	24	23	20
180	21	21	21	21	20

Example 12 produced no change in Ra and almost no change in Rz, probably because there was not a sufficient amount of abrasive particles present to provide the necessary cut rate.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to the illustrative embodiments set forth herein.

## CLAIMS

What is claimed is:

1. An abrasive article comprising a plurality of abrasive composites attached to a backing, said composites comprising abrasive particles and hollow spheres dispersed in a binder, wherein said abrasive particles comprise at least about 10 vol. % and said hollow spheres comprise at least about 15 vol. %, respectively, of the total volume of said composites.
2. The abrasive article of claim 1, wherein said hollow spheres comprise at least about 25 vol. % of the total volume of said composites.
- 15 3. The abrasive article of claim 2, wherein said hollow spheres comprise at least about 35 vol. % of the total volume of said composites.
- 20 4. The abrasive article of claim 3, wherein said hollow spheres comprise between about 35 vol. % and 50 vol. % of the total volume of said composites.
- 25 5. The abrasive article of claim 1, wherein said hollow spheres have a diameter of from about 4 to about 250 micrometers.
- 30 6. The abrasive article of claim 1, wherein said hollow spheres have a median diameter of from about 25 to about 125 micrometers.
- 35 7. The abrasive article of claim 1, wherein said hollow spheres each comprise a shell having thickness of from about 3 to about 15% of the overall diameter of said hollow sphere.

8. The abrasive article of claim 1, where said abrasive particles are selected from the group consisting of fused aluminum oxide, ceramic aluminum oxide, silicon carbide, chromia, alumina zirconia, diamond, tin oxide, iron oxide, 5 ceria, cubic boron nitride, titanium diboride, boron carbide, silica, garnet, and combinations thereof.

9. The abrasive article of claim 1, wherein said hollow spheres comprise shells formed of a material selected from 10 the group consisting of glass, ceramic, thermoset resin material, and thermoplastic material.

10. The abrasive article of claim 1, wherein said hollow spheres comprise shells formed of material selected from 15 the group consisting of glass, fly ash, alumina, clay, phenolic resin, polyvinylidene dichloride, polyolefin, and polyurethane-polyurea.

11. The abrasive article of claim 1, wherein said hollow 20 spheres comprise ceramic shells coated with a material to promote adhesion of said spheres to said binder.

12. The abrasive article of claim 11, wherein said material is selected from the group consisting of a 25 coupling agent and resins.

13. The abrasive article of claim 1, wherein said hollow spheres comprise translucent or transparent shells.

30 14. The abrasive article of claim 1, wherein said abrasive composites have a height between about 40 and 1040 micrometers.

35 15. The abrasive article of claim 1, wherein said composites are precisely-shaped.

16. The abrasive article of claim 1, wherein said abrasive composites have a shape selected from the group consisting of pyramidal, truncated pyramidal, conical, truncated conical, hemispherical, and prismatic.

5

17. An abrasive article comprising a plurality of abrasive composites attached to a backing, said composites comprising silicon carbide abrasive particles and hollow spheres dispersed in a binder, wherein said silicon carbide 10 comprises between about 10 and 25 vol. % of the total volume of said composites, and said hollow spheres comprise about 25 to 45 vol. % of the total volume of said composites.

1/2

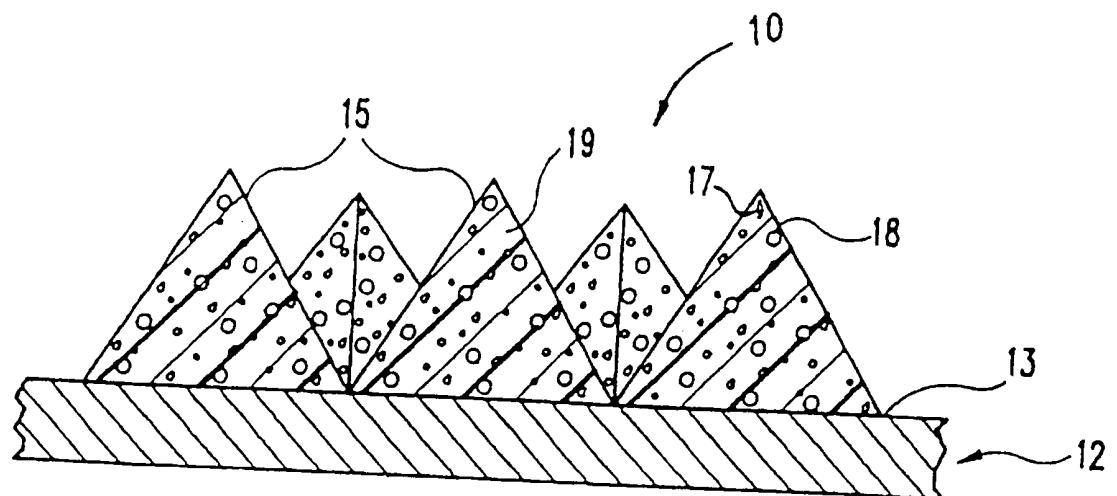


FIG. 1

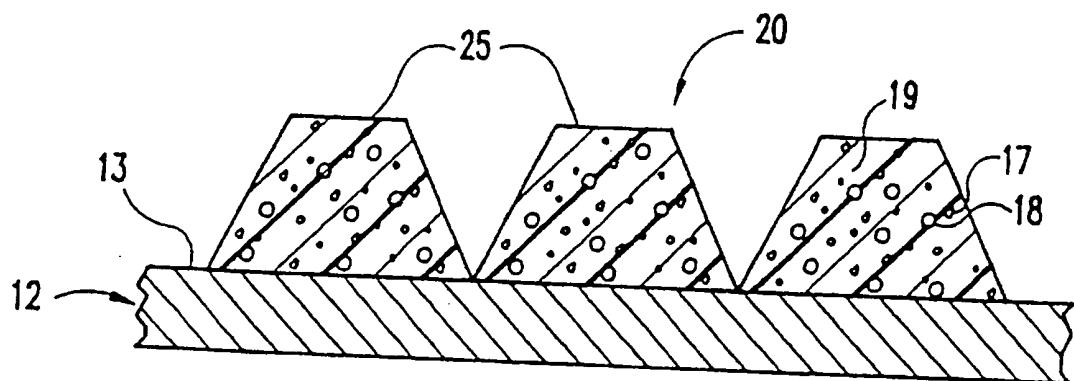


FIG. 2

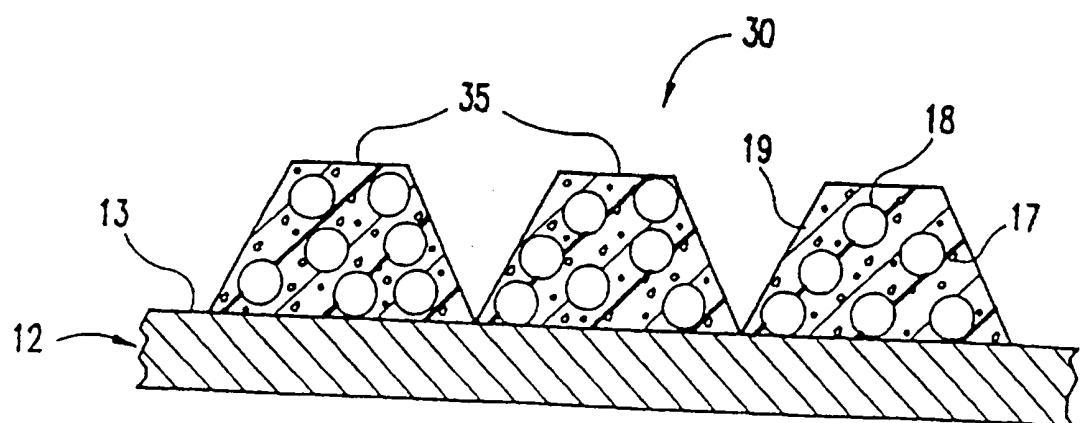


FIG. 3

2/2

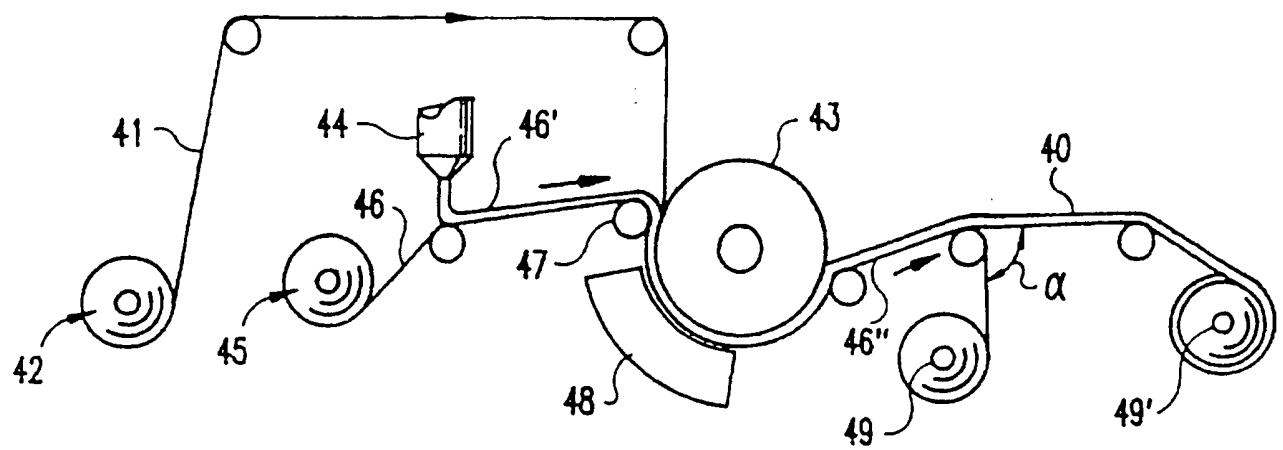


FIG.4

# INTERNATIONAL SEARCH REPORT

Int. Search Application No

PCT/US 96/12110

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 B2403/28 B24D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 B24D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 799 939 A (ULRICH BLOECHER ET AL) 24 January 1989 cited in the application	1-10, 13-15,17
Y	see column 3, line 33 - column 4, line 37; figures 1,2 ---	11,12,16
X	EP 0 444 824 A (MINNESOTA MINING AND MANUFACTURING COMPANY) 4 September 1991 cited in the application see page 4, line 3 - line 4; claims 1,3,7,15; figures 5,6 ---	1
Y	WO 95 07797 A (MINNESOTA MINING AND MANUFACTURING COMPANY) 23 March 1995 cited in the application see page 27, line 5 - line 19 see page 28, line 11 - line 16; claims 1,3,6,7 ---	11,12,16
		-/-

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

\* Special categories of cited documents :

- \*'A' document defining the general state of the art which is not considered to be of particular relevance
- \*'E' earlier document but published on or after the international filing date
- \*'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*'O' document referring to an oral disclosure, use, exhibition or other means
- \*'P' document published prior to the international filing date but later than the priority date claimed

\*'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

\*& document member of the same patent family

1

Date of the actual completion of the international search

Date of mailing of the international search report

11 April 1997

24.04.97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL-2280 RZ Delft

Authorized officer

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 96/12110

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95 11773 A (MINNESOTA MINING AND MANUFACTURING COMPANY) 4 May 1995 see page 14, line 16 - line 21; claim 1; figures 1,2 ---	1-17
A	WO 95 01241 A (MINNESOTA MINING AND MANUFACTURING COMPANY) 12 January 1995 see page 18, line 22 - page 19, line 35; claims 18-23; figures 1-3 ---	1
A	GB 896 910 A (THE CARBORUNDUM COMPANY) 23 May 1962 see claims 1,6,7 ---	1,8-10
A	US 3 661 544 A (NOBLE D. WHITAKER) 9 May 1972 see claims 1-3,7 ---	1,8-10
A	US 2 806 772 A (NORMAN P. ROBIE) 17 September 1957 see column 6, line 17 - line 23; claims 1,2,8; figure 3 ---	1,8-10
A	EP 0 418 738 A (NORTON COMPANY) 27 March 1991 see claim 15 ---	1
A	EP 0 396 150 A (NORTON COMPANY) 7 November 1990 see page 13, line 35 - line 38; claims 1-5,12 ---	1,13
A	EP 0 664 187 A (DAI NIPPON PRINTING CO., LTD.) 26 July 1995 see claims 1,13; figure 1 -----	1,13,15

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International Application No  
PCT/US 96/12110

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 4799939 A	24-01-89	AU 1115588 A EP 0280463 A		01-09-88 31-08-88
EP 444824 A	04-09-91	US 5039311 A AU 637669 B AU 7028491 A CA 2035380 A DE 69115735 D DE 69115735 T ES 2081429 T		13-08-91 03-06-93 05-09-91 03-09-91 08-02-96 08-08-96 01-03-96
WO 9507797 A	23-03-95	AU 6164394 A CA 2170989 A CN 1141016 A EP 0720520 A JP 9502665 T NO 961011 A ZA 9400585 A		03-04-95 23-03-95 22-01-97 10-07-96 18-03-97 13-05-96 27-07-95
WO 9511773 A	04-05-95	US 5454844 A AU 7874594 A BR 9407904 A CA 2173853 A CN 1133575 A EP 0725706 A		03-10-95 22-05-95 19-11-96 04-05-95 16-10-96 14-08-96
WO 9501241 A	12-01-95	US 5549962 A AU 672316 B AU 6953194 A BR 9406987 A CN 1126454 A EP 0706440 A JP 8512074 T US 5500273 A		27-08-96 26-09-96 24-01-95 12-03-96 10-07-96 17-04-96 17-12-96 19-03-96
GB 896910 A		NONE		
US 3661544 A	09-05-72	BE 759502 A CA 946168 A DE 2058475 A		27-05-71 30-04-74 09-06-71

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 96/12110

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3661544 A		FR 2072481 A GB 1276633 A	24-09-71 07-06-72
US 2806772 A	17-09-57	NONE	
EP 418738 A	27-03-91	US 5037453 A US 5110322 A CA 2025177 A DE 69016327 D DE 69016327 T ES 2066923 T JP 2523971 B JP 3178775 A	06-08-91 05-05-92 14-03-91 09-03-95 10-08-95 16-03-95 14-08-96 02-08-91
EP 396150 A	07-11-90	US 5014468 A AU 621741 B AU 5450190 A CA 2015720 A,C JP 3073276 A JP 7080123 B	14-05-91 19-03-92 08-11-90 05-11-90 28-03-91 30-08-95
EP 664187 A	26-07-95	WO 9427787 A	08-12-94

